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Domestic Robots and the Dream of Automation: Understanding Human Interaction and Intervention

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ABSTRACT

Domestic robots such as vacuum cleaners or lawnmowers are becoming popular consumer products in private homes, but while current HCI research on domestic robots has highlighted for example personalisation, long-term effects, or design guidelines, little attention has been paid to automation. To address this, we conducted a qualitative study with 24 participants in private households using interviews, contextual technology tours, and robot deployment. Through thematic analysis we identified three themes related to 1) work routines and automation, 2) domestic robot automation and the physical environment, as well as 3) interaction and breakdown intervention. We present an empirical understanding of how task automation using domestic robots can be implemented in the home. Lastly, we discuss our findings in relation to existing literature and highlight three opportunities for improved task automation using domestic robots for future research.

CCS CONCEPTS

• **Human-centered computing → Field studies**; **Empirical studies in HCI**.

KEYWORDS

human-robot interaction; domestic robots; domestic robot automation; interventions to domestic robot breakdown

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1 INTRODUCTION

People increasingly encounter and interact with robots as these become pervasive in today's societies. The variety of contexts in which robots can be encountered (e.g. industrial for manufacturing, tutoring and education) highlights the importance of a well-founded understanding of how people interact with this type of technology. The current trend towards an increase in the numbers of robots has been estimated to grow from 17.2 million to 33.1 million units sold from 2020 to 2025 [33]. This has prompted researchers in HCI to investigate and study interaction with robots in numerous settings. As examples, HCI research has studied robots in shopping malls [16, 21, 24], museums [37, 39, 49], exhibitions [29, 32], the education sector [8, 26, 34, 36] as well as in the domestic space [12, 20, 35, 38, 43, 44].

Automation of work tasks (trivial, complex, repeated, etc.) has been one of the major drivers behind the widespread diffusion of robots (i.e. the removal of manual tasks [2]). This includes examples like teleoperation with partial autonomy (e.g. [17, 23]), elder-care (e.g. [18, 19]) autonomous tutoring systems (e.g. [6, 8, 9]) or collaboration with (semi-)autonomous collaborative robots (cobots) in industry (e.g. [28, 31]). For example, Davison et al. [8] found that automation using robots in the tutoring context, is a feasible way to personalise the learning experience for children. They demonstrated that children can progress unsupervised through the curriculum using an automated tutoring robot. Hanheide et al. [18] showed that an autonomous robot in an elder care home can develop a model, providing the right information at appropriate time and place to the elderly, thereby gradually increasing the amount of successful interaction over time. However, this focus on automation appears to have less research interest for robots in the home.

Domestic robots like vacuum cleaners or lawnmowers are becoming popular consumer products, for example in 2020 11% of Danish households had a vacuum robot, and this number is constantly increasing [40]. HCI research has investigated domestic robots over a decade (e.g. [10, 11, 14, 43, 46, 47]), and have focused on physical personalisation [43, 46], change of cleaning behaviour [12], importance of the introduction to the technology [14], long-term effects [11], or the development of design principles or recommendations [10, 46]. But somewhat surprisingly, there has been limited focus on automation for domestic robots in HCI research, even though that many (or perhaps even most) domestic robots aim to automate domestic work tasks like mowing the lawn or vacuum cleaning. Studies have already highlighted the importance of effective automation of smart appliances, such as heating or washing machines, in the home (e.g. [5, 27, 50]), yet research considering automation *of* domestic robots are few. Yang et al. [50] show that for successful automation in the home to be implemented several other prerequisite have to be met. These include an interconnectivity with other devices, the users home environment, as well as reliability of the device in question. A recent example investigation effective automation of tasks through robots in the domestic settings is Verne [47]. They investigated the adaptation of lawn mowing robots and how this affected old and new work tasks in the garden. Verne calls for further research on work and adaptation of robots in domestic settings.

To address automation and domestic robots, we conducted a qualitative study with 24 participants, carried out as interviews, contextual technology tours [1] as well as robot deployment. We identify three primary themes related to 1) work routines and automation, 2) domestic robot automation and the physical environment, and 3) interaction and breakdown intervention. Based on these we discuss several implications for future research. Our work aims to make the following contributions: a) An empirical understanding of domestic robots in private households with particular focus on automation, and b) opportunities and design implications for enabling automation in domestic settings.

2 RELATED WORK

In this section, we highlight literature investigating domestic robots in the context of the home as well as literature focusing on automation in and outside of the home.

2.1 Interacting with Domestic Robots

HCI research on domestic robots (e.g. [11–14, 25, 43–47]) has investigated topics such as the comparison of regular vacuum cleaner in contrast to vacuum cleaning robots [12], what values are created through robot use [14], adoption behaviour of a domestic robot [47], as well as cosmetic personalisation of the domestic robot (e.g. [43, 46]).

Forlizzi and DiSalvo [14] conducted a longitudinal ethnographic study for four months. Firstly, they found the importance of the way the technology is introduced to the household since the way it is introduced can have a strong effect on the usage and feeling of responsibility towards the technology by the individual members of the household. Further, they present the need of the user to adapt the home to effectively facilitate the robot in completing its task. Lastly, the present potential of a robotic vacuum cleaner to transform the cleaning task into a social activity between the users and the robot, thereby transforming a task which previously was considered boring and mundane. This not only has an impact on the activity itself but also the cleaning practices and the frequency of cleaning.

A following longitudinal ethnographic study by Forlizzi [12] compares the impact on six families when given a Roomba vacuum cleaner or manually operated vacuum cleaner. While the classical vacuum cleaner led to the task of vacuuming being a "one person task", the introduction of the Roomba introduced a new way of cleaning, transforming the cleaning task to a social activity including the entire household. While the vacuuming robot investigated was used while the users were co-located, it opened up for the possibility to complete other tasks in the household such as dusting while the floor was being taken care off. Thereby the domestic robot increased the efficiency of the cleaning routine. Further, the vacuum robot changed the households cleaning routines from a planned to an opportunistic activity, in which the user activated the robot whenever the need arises, thereby leading to a higher degree of flexibility. The impact of the Roomba on the household was further expressed by the fact that two of the three families who received the Roomba got entirely rid of their classical vacuum by the end of the study.

Sung et al. [45] investigated the type of user of the domestic robot, as well as typical cleaning and non-cleaning related use-cases in the home. They concluded that over 90% of the users had a higher degree (undergraduate or graduate degree), no difference in adoption of the Roomba and gender could be identified. Further, it has been investigated how people physically adapt their Roomba, thereby making use of personalisation [43, 46].

An alternative approach is investigated by Elara et al. [10]. They focus on a robot centred approach, and instead of adapting the robot to the user's needs, they investigate how users can change their behaviour and environment to be more robot inclusive. They refer to the change as a change from "designing robots" to "designing for robots" of artefacts or the environments. They conclude with four design principles (observability, accessibility, activity and safety) to facilitate robot inclusive space, and thereby transform the home to a robot friendly environment.

In addition to the robotic vacuum cleaners, other domestic robots have been studied as well. One example is Verne [47] who, using autoethnography, studies the impact the introduction of a robot lawnmower has on gardening. Of particular interest is the removal, and addition, of tasks due to the introduction of the automation of the lawn mowing. The study highlights the importance of balance between the addition of new tasks, and the demands these have on the work the robot owner has to perform. In the case of [47], the addition of the lawn mowing robot resulted in the reduction of manual gardening tasks, but in the increase of engineering and electrician related tasks. Further, the efforts needed to make the garden robot-friendly resulted in unanticipated changes to the layout of the garden.

While multiple studies exist investigating domestic robots of varying kinds [12, 14, 44, 47], to the best of our knowledge no study has yet investigated the challenges related to the process of task automation in the home using domestic robots, and the user interventions to occurring problems and breakdowns.

2.2 Automation

We present work relating to home automation with non-robotic technology as well as task automation using robots in a variety of different contexts.

2.2.1 Home Automation. A multitude of HCI research has investigated automation in home (e.g. [3, 5, 15, 30]). Topics of interest include feeling of loss of control [3], important aspects of home automation [5], or responsibility sharing in multi-user smart homes [15].

Brush et al. [5] identified three aspects in households using home automation, namely *convenience*, *peace of mind* and *centralised control*. Particularly convenience was often identified as highly important. The possibility to remotely monitor if the front door was locked, and lock it if this was not the case, was perceived as convenient while simultaneously providing peace of mind and security to the participants. The primary type of automation employed in the households were time or event-based automation (i.e. "Do X at 1 PM", "Activate light when the motion sensor detects..."). While participants perceived the augmentation of the home for automation as beneficial, participants almost uniformly stated that it was not robust enough for broad market adoption.

Bittner et al. [3] investigate the potential downside of augmenting the home to allow for more automation. The automation of tasks in the households can lead to the undesirable feeling of loss of control as well as remove healthy practices throughout the day, such as caring for a plant. While not arguing against automation in the home in general, Bittner et al. argue for a careful selection of what, and how, to automate.

Geeng and Roesner [15] investigate smart home usage of 18 participants and their households. They make use of interviews as well as experience sampling to get a nuanced picture of topics related to device selection and installation, device usage, technology breakdowns as well as long-term changes. They could identify, that typically one household member was responsible for the technology. This was typically due to lack of interest or technical ability by the other household members. While not the primary tendency, Geeng and Roesner identify some households concerns with privacy related to the additional data collected to facilitate the functionality provided by the digital artefacts in the smart home.

2.2.2 Automation with Robots. Task automation using robots has been investigated in numerous domains. Examples include public spaces for human-lile approaching behaviour [23], support for elderly with dementia [19], or lack of adaptation to the human coworker in industry [31].

Kato et al. [23] investigated human-like polite approaching behaviour of an autonomous robot in a shopping mall. They developed a model to mimic human-human approaching behaviour and compared this to a pro-active (i.e. approach everyone in range) and passive (i.e. only engage when approached) condition. They demonstrated that the model based approaching behaviour led to a less intrusive and successful interaction initialisation. They could demonstrate that an autonomous robot can be useful for automatic pedestrian intention recognition, thereby opening up for the possibility to replace or support human service staff members in public contexts.

Hebesberger et al. [19] conducted a study in an elder care home in which they investigated the possibility for an autonomous robot to participate in weekly walking groups with elderly with dementia to support staff-shortage. They could identify the autonomous robots potential to increase motivation as well as overall mood within the group while walking. While the autonomous robot adds a multitude of positive aspects to the walking group, robustness and reliability of autonomous systems are highlighted as potential weak spots. The occurrence of problems and breakdowns of the robot had a negative effect, since they were causing additional workload for the therapist.

In the industrial domain (e.g. manufacturing) there has been a focus on automation with cobots. One recent example is the study by Michaelis et al. [31]. Through interviews with nine experts in the manufacturing domain about their experience with cobots, they identify that while collaboration happens, this is still on a very low-level (e.g. starting/stopping). Apart from this, the robots would typically work autonomous, limiting the adaptation to the individual worker and situation. They present findings pointing towards the lack of emphasis for human control and adaptation *to* the human, i.e. the cobot becomes *"...solely as a piece of an automation solution."* [31]. To improve on this both the cobot would need to adapt, as well as the skill-set of the human operator.

3 STUDY

With an increasing amount of domestic robots (vacuuming robots, hybrid robots combining vacuuming and floor mopping, and lawn mowing robots) in households, with increased complexity and ability to automate manual tasks, we see a need arise to understand opportunities, challenges and breakdowns related to the interaction and automation in the context of the home. The following section will start by describing the participants as well as the recruitment process. This is followed by a presentation of the three distinct methods for data collection. Lastly, this section will describe the data analysis.

3.1 Participants

We recruited 27 participants (22M, 5F) from 24 households located in Denmark. Inhabitants had an age ranging from 25 to 54 (average: 34.9, std: 7.5). The participants came from twelve families (with 2 adults and at least one child), seven couples without children, and five singles, two of which lived together with a child. In most households (21/24), we interviewed one participant who, according to self-assessment, had the primary responsibility for the domestic robot(s). For the last three households, we interviewed both inhabitants as they both considered themselves as users of the robots. The participants will be referenced using P1 - P24. The three households with two interviewees (P13, P22, P23), the same label will be used for referencing both interviewees.

Over half of the households (13/24) used more than one domestic robot. The most common type was a hybrid robot (17/24), followed by lawn mowing (13/24) and exclusive vacuuming robots (6/24). The households owned 21 different robot models, six vacuuming robots, five hybrid models, and ten different lawnmower models. The number of days the households operated at least one domestic robot varied greatly between the households, ranging from once a week (e.g. P17) to multiple times every day (e.g. P5). Most of the participants were living in houses (17/24) whereas the remaining seven participants were living in apartments. Accommodations were between one to three levels and ranged in size from 60m^2 up to over 300m^2. For households who had a lawn mowing robot, we further inquired about the size of their garden which ranged from 100 m^2 (e.g. P21) to over 5000m^2 (P5). Robot owners had a wide variety of employments and incomes, and assumed positions such as including academic positions, unemployed, graphic designers, butcher, students, teachers, software developers or electricians.

All households had access to at least one smartphone (Android or iOS) whereas most households further had access to at least one type of personal assistant (Google Assistant, Alexa or Siri). This was typically provided through separate digital artefacts such as the Amazon Dot/Echo, Google Nest Hub or as part of their smartphone (e.g. Siri or Google Assistant). Multiple households had custom solutions (e.g. through Raspberry Pi) or made use of third party applications (e.g. IFTTT or FloleVac) to increase the complexity of the functionality provided.

Participants were recruited through personal networks of the authors, flyers in apartment buildings, snowballing, as well as multiple Facebook groups for people who own domestic robots, after receiving approval from the respective site administrator. These included both groups for people with interest in domestic indoor as well as outdoor robots. All participants were unpaid. A complete listing of participants characteristics can be seen in Table 1.

3.2 Data Collection Methods

We used a multiple method approach to collect data from different perspectives concerning the efforts to achieve efficient task automation, as recommended in research investigating interaction with robots [19]. Specifically we made use of online interviews (Section 3.2.1), contextual technology tours [1] (Section 3.2.2) as well as robot deployment (Section 3.2.3) of domestic robots with regular visits. Furthermore, we collected additional documentation in the form of photographs, screenshots, videos and participant notes. Lastly, participants of the robot deployment (P22, P23, P24) were asked to keep a diary.

During the recruitment process, we asked preliminary questions to prepare the semi-structured interview for the individual household. The overall interview structure was the same for all households. It consisted of five topics, namely: 1) The devices used by the households, 2) the infrastructure in relation to the domestic robots (e.g. personal assistants, or use of third party applications), 3) the interaction with the devices and systems (e.g. who interacted when, where with what), 4) the perceived usefulness of the system(s) and devices, as well as 5) problems and breakdowns of varying kind leading to the need to adapt. For each topic, multiple questions were prepared but additional questions were asked depending on the response given. Deviations could arise depending on the technological ecosystem in the individual household. Further, these informal initial questions helped to identify the main interaction partner in the household for the domestic robot. For all data collection approaches the first step was providing some background information about the study following the signing of informed consent. In the case of phone/Skype interviews, informed consent was given verbally.

3.2.1 Interviews. We interviewed 12 participants (P1 - P12) using an online semi-structured approach using phone calls, Skype (Phone/Skype) or alternative means of online communication. The addition of Phone/Skype interviews was chosen as an alternative approach to the contextual interviews due to geographical distance as well as restrictions of face-to-face contact during the national lock-down due to the COVID-19 pandemic. All interviews were based on an interview guide developed during pilot testing and revolved around five broad topics as presented in Section 3.2.

3.2.2 Contextual Technology Tour. We recruited an additional 9 participants (P13 - P21) for contextual technology tours in the participants household [1]. The technology tour was accompanied by informal conversation and followed up by a semi-structured interview in the same manner as described in Section 3.2.1. The structure of the technology tour was inspired by the technology tour checklist, as presented by Baillie et al. [1], thereby the technology tour served as an anchor point for contextualisation of the presented technology and the usage thereof. Amongst other topics, we asked the participants to demonstrate the robots as well as supporting technology, e.g. Alexa or associated applications. Furthermore, participants demonstrated where the corresponding robot would operate, modifications done to the household/garden to facilitate the robot, as well as problem areas and how they intervened to solve those problems. During the technology tour an informal conversation was held, notes were taken to inquire further information during the following semi-structured interview.

3.2.3 Robot Deployment. Lastly, we made use of robot deployment to collect data for novel robot users without previous experience. For this purpose, we deployed the Xiaomi Roborock S6MaxV (S6MaxV) robot to 3 additional participants (P22 - P24) for ten consecutive days each. The S6MaxV is a hybrid robot with both vacuuming as well as floor mopping capabilities. It supports virtual no-go-zones, virtual walls, scheduling, remote control with live HD camera feed, as well as Google Assistant and Alexa integration. Furthermore, multiple applications (e.g. Roborock or Mi Home) supporting the robot are freely available, thereby giving the participants the possibility to use a variety of different apps, depending on own curiosity and preference, for the robot. For the selection of households, two requirements had to be met: 1) The household had prior to the study never owned a domestic robot and 2) at least one smartphone in the home supporting the Roborock App. Being the official app we decided on this one for the initial setup during the first home-visit. If the household had access to personal assistants, such as Alexa or Google Assistant, this was preferred but not mandatory. In cases were the household did not have a personal assistant, we supplied the household with a Google Home.

On the first day, the hardware was set up and connected to the official Roborock application. For this process, the first author of the paper was present to assist with eventual occurring problems or questions. In alignment with the findings presented by Forlizzi and Disalvo [14], the robot was introduced to all participants of the household in order to prevent the feeling of singling someone out as responsible for the robot. Furthermore, during the initial interview, we inquired information about the participants' expectations towards the robot and how they thought it would affect the amount of work required to maintain a clean home. No concrete task was given, other than using the robot as desired. Further, the participants were encouraged to document using pictures, videos, screenshots as well as writing a diary. For this purpose, every household received a notebook, post-it and some additional writing supplies for handwritten notes, but the option on how to document (digital or physical notes) was left to the individuals own preferences. Each

ID	Inhab. (children)	Age (children)	Type	Robot model(s)	Time owned
Interviews (see Section 3.2.1)					
P1	2 (3)	41, 41, (7, 9, 12)	House	Robotic lawnmower	6 months
P2	2 (2)	30 , 33 (5, 7)	House	Hybrid robot, Robotic lawnmower	2 years
P3	2 (3)	40, 42 (7, 10, 14)	House	Hybrid robot, Robotic lawnmower	2.5 years
P4	2 (1)	37, 37 (12)	House	2 × Hybrid robot, Robotic lawnmower	2 years
P5	2 (0)	35, 59	House	Hybrid robot, 2 × Robotic lawnmower	4 years
P6	1 (1)	29 (3)	Apartment	Hybrid robot	6 months
P7	2 (3)	39, 39 (7, 9, 12)	House	Hybrid robot, Robotic lawnmower	18 months
P8	2 (3)	39, 39 (8, 14, 16)	House	Hybrid robot, Robotic lawnmower	3 years
P9	2 (0)	29, 34	House	Hybrid robot	2 years
P10	2 (0)	45, 49	House	Hybrid robot	1 month
P11	2 (2)	27, 27, (<1, 2.5)	House	Hybrid robot, Robotic lawnmower	7 years
P12	2 (2)	35, 36, (3, 6)	House	Hybrid robot, Robotic lawnmower	10 years
Contextual Technology Tour (see Section 3.2.2)					
P13	2 (0)	25, 27	Apartment	2×Vacuuming robot	8 years
P14	1 (1)	54 (16)	House	Vacuuming robot	4 years
P15	1 (0)	31	Apartment	Vacuuming robot	3 months
P16	2 (3)	32,34 (<1, 3, 6)	House	Vacuuming robot	1.5 years
P17	1 (0)	34	Apartment	Hybrid robot	2 weeks
P18	2 (1)	40, 42 (6)	House	Hybrid robot, Robotic lawnmower	6 Years
P19	2 (0)	31, 32	House	Vacuuming robot, Robotic lawnmower	4 years
P20	2 (2)	37, 39, (7, 9)	House	Vacuuming robot, Robotic lawnmower	8 months
P21	2 (2)	32, 32 (4, 6)	House	2×Hybrid robot, Robotic lawnmower	18 months
Robot Deployment (see Section 3.2.3)					
P22	2 (0)	25, 28	Apartment	Hybrid robot (provided)	N/A
P23	2 (0)	26, 28	Apartment	Hybrid robot (provided)	N/A
P24	1 (0)	44	Apartment	Hybrid robot (provided)	N/A

Table 1: Key characteristics of the participating households sorted into the three data collection approaches: Interviews, Contextual Technology Tours and Robot Deployment.

household was informed that they could consider the robot theirs for the next ten days and that they were allowed to use alternative apps and integrations if they felt that would be useful (e.g. Google Assistant, Mi Home, IFTTT, Alexa etc.). The second home visit occurred ~5 days after the initial meeting. The third and final home visit occurred after 10 days. For later analysis, the conversations for all three visits were audio-recorded for each participant.

3.3 Data Analysis

All interviews and informal conversations were audio recorded (a total of ~19 hours) for later transcription and open coding during the thematic analysis [4]. The initial step was automatic transcription using konch.ai service (https://konch.ai). The automatic transcription highlights phrases of uncertainty which were manually corrected. Following the transcription, we familiarised our selves with the data by reading the transcribed interviews. During this process, initial codes were generated based on their presence in the data, for this an open coding [42] approach was used to limit ourselves as little as possible during the initial selection of codes. Example codes that were generated include "co-located interaction" or "notifications". Individual quotes were identified and written on digital post-it notes using the post-it® application. In some instances, screenshots or photos illustrating a concept were also associated with codes (the participants supplied a total of over 220 pictures). Each note contained a sentence, phrase, picture or word (e.g. *"It is scheduled [using the App] to clean twice a week by itself, Monday and Friday at 10 AM"* - **P13**). Each post-it was then associated with a code representing a concept, e.g. the code *"Automation"*. Codes were developed throughout the analysis of the interviews. Following this, we grouped codes into themes. The process of generating themes iterative and repeated three times. This process ended with the three primary themes presented in Section 4.

4 FINDINGS

In this section, we present the three key findings identified in our study. The three themes are related to 1) work routines and automation, 2) domestic robot automation and the physical environment, as well as 3) interaction and breakdown intervention.

The first theme investigates the fragmentation of one coherent task, such as cleaning or lawn mowing, into multiple sub-tasks. Further, we present our findings on how households change their behaviour and introduce new routines in order to facilitate efficient automation of the main sub-task, e.g. vacuuming or lawn mowing. The second theme presents our findings on the households adaptation to the environment, thereby intervening into potential breakdowns during the automated robot task completion, resulting in manual work. The third theme presents ways in which households changed their interaction, such as remote monitoring and controlling behaviour, as well as approaches using other digital artefacts to intervene in breakdowns.

We identified that all participants robots operated from once per week (e.g. P17), up to a maximum of multiple times every day (e.g. P5, P22). All 24 participants made use of the official supported application whereas some participants made use of third-party applications for additional functionality. The households have had domestic robots for varying amounts of time (see Table 1), except the households participating in the deployment, for which the domestic robot was entirely new. Households typically upgraded after several years due to the desire for newer functionality or a more recent model supporting more intelligent behaviour as well as increased connectivity to other devices. All participants had access to at least one recent model of the domestic robot (2017 or newer) that supported interaction through other devices (e.g. personal assistants, google home routines, or smartphone applications).

Quotes from individual participants will be referenced using labels from P1 – P24. All quotes are translated to English, as the interviews were conducted in either Danish, German or English.

4.1 Work Routines and Automation

For all three types of domestic robots included in this study (i.e. vacuuming, hybrid and lawn-mowing) the motivation for buying a robot was the same for all participants, excluding the P22 - P24 in the robot deployment, namely: *automating an undesirable and time-consuming task*. While not all households used the exact word "automation", the statements were related to the desire to remove a manual task through the robots ability to automate it, examples statements include *"...you don't have to use time on it [the cleaning] manually, this really saves time..."* - **P10**, or *"...this was probably the best investment for the house we have made...we save so much time by not having to clean manually. It just gives a lot of time"* - **P11**.

The task of vacuuming or lawn mowing was, before the domestic robot, seen as one coherent task. This included the preparation of the area to be cleaned/mowed, the cleaning/mowing itself, and the maintaining of the robot. All households observed that the robot fragmented this one coherent task into smaller sub-tasks. P16 for instance described the necessity for preparation, *"...it [successful cleaning] also requires that no socks or anything is lying around on the floor."* - **P16**). The sub-tasks are related to 1) larger changes in the environment of the robot and setup, 2) preparation and maintenance, as well as 3) the cleaning/mowing itself. Regardless of the type of domestic robot investigated during this study, the robot was only able to complete the main task namely the cleaning/mowing itself. This fragmentation of tasks, and the robots ability to only complete a subset thereof, lead to the necessity to adopt new routines to facilitate successful task automation. This resulted in a change of cleaning related task from manual labour (i.e. the floor cleaning or lawn mowing) to a more preparatory and maintaining nature. While most households (pre-purchase) were aware that the domestic robot would require some setup, some households expressed surprise about the frequency of these additional sub-tasks that the robot is *not* able to complete.

Although not the primary reason for purchase, all households observed a noticeable improvement of the result that all types, both indoor and outdoor, of robots delivered. **P2** stated about their hybrid robot that *"...the floor is cleaner than before since we clean more frequent"*. Due to the simplicity of the cleaning/mowing initiation, as well as the possibility to clean/mow automatically while not at home, all households observed an increase in cleaning/mowing frequency. All 13 households who had a lawnmower reported a drastic increase in the operation of the lawnmower, with the lowest frequency being P18 with two to three operations a week. In the case of the vacuuming and hybrid robots, this increasing tendency was even stronger. 23 households, except P17 which was just as previously once a week, described a drastic increase in the number of vacuuming runs, in some cases even to seven or more runs a week (e.g. P5, P21, P22).

P20, for instance, described that the density of the grass improved after the purchase of the lawn-mowing robot, which was operating at least five times a week, further it reduced the amount of moss in the lawn and in general resulted in a more well maintained and consistent lawn. The same was observed for the vacuum and hybrid robots inside (e.g. P19, P22). Even though the vacuum robot was not able to drive under the living room couch, the amount of dust accumulation was passively reduced just through the cleaning in the remainder of the house.

> *"Before buying it, we really hoped that it could get under the couch, which we found out was not the case. We had the hope that, just by it driving so frequently, the dust and dog hair level in the entire house [including places it can't reach] will be reduced. This is definitely the case!"* - **P19**

While the task fragmentation, from *one* coherent to *three* sub-tasks, leads to an increase in cleaning/mowing, in some households from weekly to daily (e.g. P21, P22), this resulted in a corresponding increase in the frequency of the related preparation and maintenance tasks. The strongest increase was observed for the floor mopping functionality provided by the hybrid robots. The floor mopping frequency increased in some households from monthly cleaning to multiple times a week (e.g. P22) or even daily (e.g. P5). Even though this led to an increased need for preparation and maintenance, this type of work was preferred, and in contrast to the actual cleaning/mowing activity described as a valuable task. P20 described the maintenance related work as satisfying and enjoyable. The satisfaction of maintaining the two households robots comes from seeing them perform their task better, thereby removing the need to perform the manual task theme selves.

> *"...to vacuum dirt from the floor is a real annoying s**t task - the robot deals with that, and while I know that maintenance is an often recurring task, I feel that it is way more satisfying work [compared to the manual vacuuming/lawn-mowing]. It gives me satisfaction to clean the vacuum robot when it is completely clogged... After maintaining it you can see, it just works!"* - **P20**

The majority of the households had to adapt their home/garden, introduce new routines, or adjust their way of life in their home to facilitate the robot (e.g. P14, P15, P16, P19, P21). The most frequent new routines spanned from de-cluttering the entire floor before every operation (see Figure 1c), to a behaviour change, leading to no cluttering at all. The failure of the introduction of these new cleaning routines, namely performing the preparatory work, led to the inability of the domestic robot(s) to perform their task successful without encountering breakdowns. In some cases even to the destruction of property in addition to the failure of the operation, as illustrated in Figure 1a, here the failure of clearing the

(a) (b) (c)

Figure 1: (a) The participant neglected to prepare the lawn for mowing resulting in the destruction of a towel, as well as a breakdown of the robot requiring manual correction. (b) Cables and a bag under the desk were not removed before remote activation of the robot, resulting in a error notification and the robots failure to clean. (c) The household introduced a new morning routine through the house, preparing the cleaning run by de-cluttering the house.

lawn resulted in the destruction of a towel as well as the need for manually assisting the robot. These breakdowns, or lack in adaptation or intervention to facilitate the robot, in some cases, led to the restriction of exclusively co-located operation, thereby removing the option for remote operation. P16, for instance, accepted the fact that the vacuum robot typically would operate while co-located. This was due to a lack of certainty about the current state, in terms of doors and clutter level, of the house:

> *"No, I never turn it on when I'm not at home. I start to doubt if I have removed clutter from the floor, so I don't really want to take any chances here. I just turn it on when I get home... when it gets into the children rooms and it sucks up something from the floor, then it just stops and notifies me that it is stuck - so the cleaning trip is wasted."* - **P16**

While both the frequency as well as the type of work related to cleaning/mowing changed, the trade-off between *work automated* to *new work created* by the acquisition of the domestic robot was still considered worthwhile. This was magnified by the increase in cleaning/mowing frequency, thereby improving the level of cleanliness in the house as well as consistency in grass level for the lawn mowing robots. While the introduction of new routines and behaviour to facilitate the domestic robots improved its usefulness, both the indoor and outdoor domestic robots required, in some cases, changes to the environment for optimal functionality.

4.2 Domestic Robot Automation and the Physical Environment

The second theme identified was the adaptation of the environment to improve the robots ability to perform its task. P18, for instance, stated that the willingness to adapt to the robot resulted in a positive trade-off, *"The better it can do its job, the less we have to do. So thereby we reduce the amount of manual work we have to do"* - **P18**. While this statement was concerning the vacuum robot, the same tendencies could be observed for the outdoor robot(s). P18, for instance, stated that the idea was not, in contrast to the vacuum robot purchase, to reduce a task, but to remove a task, namely the lawn mowing.

> *"Previously we had grass in front of the house, and also on the other side of it. We chose [due to the lawnmower purchase] to remove the grass and replace it with tiles on the side and stones in the front. Thereby we could finally say completely goodbye to the manual lawnmower."* - **P18**

The environmental change was present both for the indoor as well as outdoor context, albeit it was more prominent in the layout of the garden. All 13 lawnmower owners had to make at least minor adaptation to their garden. These ranged from digging down the trampoline (e.g. P1, P18, P20) to larger changes such as removing flower beds, replacing grass with tiles/stones (see Figure 2), or putting up new fences to prevent the robot from falling into lakes (e.g. P5, P18, P19, P20).

Although the largest changes to the environment were encountered outside the household (i.e. the garden), several participants (e.g. P4, P13) also changed the setup of the inside the household. This ranged from smaller changes, such as making sure that cables would not have ground contact (e.g. P14, P23), e.g. using cable clips, to larger changes including mounting furniture to the walls, changing the legs on couches/beds (see Figure 2), designing custom "bump absorbers" (see Figure 2), or removing the door threshold between rooms (e.g. P2, P14, P19, P21). To be able to remove the need for vacuuming in the entire house, without having to move the robots manually between rooms, P4 was willing to make changes to the house, *"We removed the doorsteps to all rooms where the robot had trouble to get into or out of."* - **P4**. By changing the environment to the robots needs, P4 effectively removed the need for manual cleaning in all rooms. This increased the perceived usefulness of task automation and remote interaction since the robot now could be remotely started without being limited to certain rooms.

About half of the participants (e.g. P2, P4, P13, P19, P21) observed that the addition of the vacuum/hybrid robot not just reduced, but removed the need for manual vacuuming cleaning. Through

(a) (b) (c)

Figure 2: (a) The participant bought new legs for the couch to make sure *"...that it gets over the magical 10cm threshold."* - P4. (b) A narrow passage led to the robot getting stuck. The participant decided to place tiles to remove the need for the robot to enter the passage. (c) One household designed custom feet for speakers to prevent the robot from scratching the speakers.

changes in the environment, participants demonstrated the willingness to make adjustments to the home to improve the robot's capabilities to perform its task. Not all domestic robot owners were willing or able to make changes to their home (e.g. P15, P16, P17, P20) to increase the robot's performance. P17, for instance, stated that while the robot could enter the bathroom, exiting it again resulted in problems.

> *"The robot cleans the entire apartment, except the bathroom. It can get into the bathroom but then it can't get out again. So I decided that the bathroom is mostly off-limit...I simply do this by closing the bathroom door before it cleans."* - **P17**

The lack of environment adaptation to facilitate the robot had two different consequences. Some households (e.g. P15, P17) decided to pick the robot up and move it manually, thereby introducing another type of manual task. The second alternative was to restrict the robot to only parts of the house, the inaccessible areas of the apartment/house would in these cases be cleaned manually (e.g. P16, P21, P22).

In some cases, the investment in new furniture, apartments or even houses was considered with careful consideration to robot friendliness (e.g. *"...we haven't changed any furniture yet, but when we buy new furniture we are making sure that it works with the vacuum..."* - **P10** or *"I knew when we build this house that we wanted a robot, so I made sure that the house was robot friendly when designing it."* - **P7**). Even though participant P22 has been looking to move to a new apartment, this process has changed after experiencing the robot in the deployment. While using the hybrid robot for 10 days, they got so used to it that they decided to purchase one themselves, this was an important consideration before signing the lease for their new apartment.

> *"We wanted to move for a long time, but now that we tried the robot we started paying more attention to things such as door thresholds and small corners in apartments we inspected. We just signed the contract for our new, and robot friendly apartment!* - **P22**

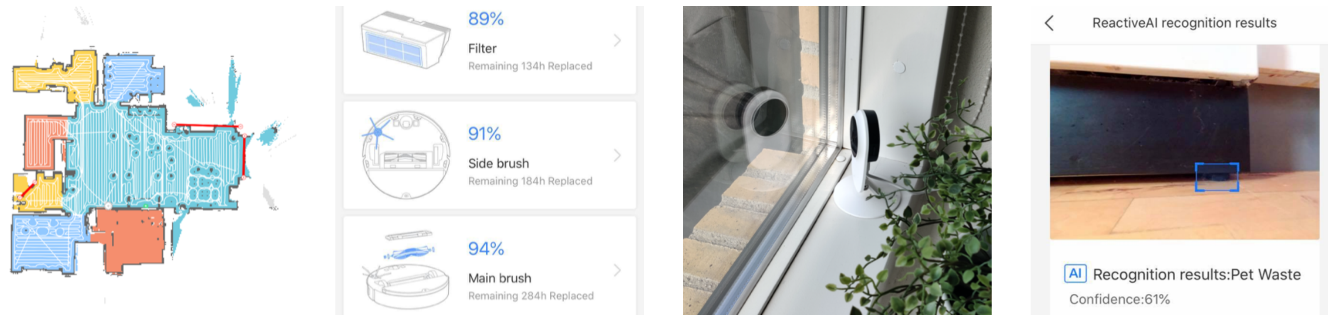
Even though it, in some cases, took quite a lot of effort to make sure that the domestic robot could operate with satisfying performance, most participants expressed that they were willing to adapt to the technology by changing its environment. This was motivated by the outlook of a removal (or at least strong reduction) of the manual mowing/cleaning task. Some households decided not to adapt the environment by changing it physically, this lead to the compromising performance of the robot, leading to more manual work. Even though participants changed the environment to improve the robots ability to complete the task automation, some problems and breakdowns still occurred. For these cases, the increased connectivity allowing for different types of interaction, such as remote monitoring and controlling behaviour, was perceived important.

4.3 Interaction and Breakdown Intervention

While participants expressed the motivation to reduce the amount of work related to the process of cleaning/mowing through automation, several households explicitly stated that connectivity with personal assistants (e.g. Google Assistant, Alexa), as well as the connectivity with application support, was a requirement. Most households stated that they wanted the robot to operate without the need for manual interference, and preferably without ever seeing or hearing the robot (*"I feel like, it is nice to have the robot, but I absolutely don't want to see it. I don't want anything to do with it!"* - **P13**). While participants expressed the desire for full automation of the task, the ability to monitor and control [7] the robot was still mentioned as a priority by most households, even when the reasons for the controlling behaviour not necessarily was clear to the participant.

> *"I bought this particular vacuum robot since it is WIFI enabled and has an accompanying app. This allows me to monitor what it does while I'm not at home. I'm not quite sure what I can use this for, but I find it very interesting to observe it."* - **P14**

The tendency to use other digital artefacts, such as applications or cameras, to be able to monitor or control the domestic robot was



(a) (b) (c) (d)

Figure 3: (a) An example screen for remote monitoring of the indoor domestic robot. (b) Screen with information about the maintenance needs of the domestic robot. (c) Camera compensating for the lack of remote monitoring functionality of the robot. (d) Participants monitoring the robot using its camera with object recognition.

observed in the majority of households, see Figures 3a - 3d. The robot monitoring ranged from simple monitoring behaviour such as reacting to notifications when it got stuck or needed maintenance to more complex scenarios such as observing it through external WIFI enabled cameras (e.g. P21). In addition to monitoring behaviour, the increased connectivity also contributed to the amount of remote controlling behaviour by controlling the robot. This allowed participants to start or stop a cleaning/mowing activity while not co-located through remote interaction.

> *"What really made us happy, especially compared to our previously vacuum robot, is that we have the ability to interact with this one remotely while we are not at home. So the robot is as unobtrusive as possible since it of course also produces some noise. So it is really nice that we can get the cleaning done while we are not at home!"* - **P19**

The addition of remote functionality was by most households perceived as a valuable addition. P10, for instance, stated that *"...it is very useful that I can start the vacuum when I start driving home from work - then it is done when I get home."* - **P10**. This tendency was observed in nearly all households. Exceptions to the remote activation were typically observed in households novel to domestic robots (P15, P22, P23), this was related to under-trust in the robot's ability. Although all households had at least one robot with the possibility for remote interaction, some participants used creative, sometimes low-fidelity, solutions to use additional digital artefacts to improve the remote interaction with their domestic robots. Since P21's lawn was quite simple, being a flat rectangle with an approximate size of 12×8 meters, P21 decided to invest in a cheaper entry-level robotic lawnmower. A side effect of this was the lack of any kind of connectivity, thereby removing the possibility to monitor or control the lawnmower remotely (scheduling was still possible on the lawnmower itself). To counter this effect P21 installed smart cameras (see Figure 3c) pointing at the lawn, thereby using additional digital artefacts to improve the possibility to monitor the lawnmower remotely.

An alternative approach was used in the two households P10 and P20. They made, on some occasions, use of other people as a proxy to interact with the robot(s). In both cases, one partner was primarily responsible for interaction with the robot(s), and while both partners had the associated application installed, and physical interaction with the robot for all robots was a possibility, it was always the same partner controlling the robot. This resulted in robot interaction through a human proxy. For both households the partner who was co-located with the robot wanted it to clean while the robot responsible partner was at not at home. In these cases, the partner in the household would call or text the robot responsible partner to get the robot cleaning run started. P10 stated that:

> *"It is primarily me who is responsible for controlling the robot, my partner has the app installed [nods approvingly from the living room], but I have a couple of messages on my phone [from her] asking me to start the robot vacuum... So this happens sometimes when she wants to vacuum while I'm not at home..."* - **P10**

While most households remotely monitored and controlled their robot while not co-located, not all robots allowed for this (at least one robot in each household did). Interestingly, the monitoring aspect of the robots did not always serve a specific purpose other than an interest in, if the robot was doing the task it was supposed to do. This tendency was observed even for participants with multiple years of domestic robot experience. Some participants made use of creative solutions, such as the interaction through other digital artefacts or other people as proxy, to improve the possibility for remote interaction.

5 DISCUSSION

In this paper, we have investigated how danish households integrate task automation using domestic robots. We used three different data collection approaches to achieve an empirical understanding of this. We illustrated that effective automation in the home requires more than just purchasing the technology and pressing start. To facilitate efficient task automation in the home, all types of domestic robots investigated in this study, required new routines, change the environment the robot had to operate in, as well as utilisation of additional digital artefacts.

5.1 Interaction with Domestic Robots

The findings presented about adaptation behaviour towards the robot were in line with Forlizzi and DiSalvo [14] who highlight the necessity for the home to adapt to the robot. In addition to the need for adaptation, we identified that the robot automation was further supported through additional devices, thereby allowing the users to schedule, monitor or control the robot, even remotely, reducing the feeling of loss of control [3]. Forlizzi [12] shows that robot interaction becomes a social task involving multiple household members, in contrast to classical vacuuming which typically was driven by one person. Our study contradicts this, as we in all but three households with more than one person (17/20) identified a strict task division. In all 17 households, one person always was responsible for the robot, this is in line with the behaviour towards other types of non-robotic technology in the home [15]. The other inhabitants had very limited interaction with the domestic robot as well as connected systems. In two households the inhabitants not responsible for the robot would even text the robot responsible partner to ask them to start the robot.

Regardless of the type of domestic robot investigated in this study, we could see that the introduction of a domestic robot, while removing work, also added new and different tasks. This is in line with Verne [47] who recently published an autoethnographic study highlighting changes in the case of the lawn mowing robot. Verne highlights the change from physical mowing task to more engineering and maintaining workload related to the task of mowing the lawn. We identified similar tendencies in relation to the shift of type as well as the frequency of work. We could identify the same tendencies for all types of domestic robots encountered during this study. Verne highlights the risk for user rejection of the technology due to a to high demand resulting in the new tasks, and competencies needed to solve them, created by the robot. While we cannot denounce that this is a possibility, none of the 24 participants was even close to consider the trade-off between type and frequency of new work created, in contrast to work automated, as a bad trade-off. Even in cases where the robot required additional work, such as carrying it to a different floor of the house/apartment, the additional task was perceived as preferable. This shows that the amount, and frequency, of work introduced by the robot, might not be the deciding factor, but that participants put more emphasis on the type of work created.

Bittner et al. [3] highlighted the need for careful consideration about which tasks to automate in the households since automation can lead to the removal of healthy tasks. Illustrated throughout our findings, see Section 4, the automation of the manual task of cleaning/mowing did not only remove tasks but also added new tasks. In addition to these findings, our findings point towards the possibility of automation to create new enjoyable tasks. Examples of this were related to the maintenance of the domestic robots, and the feeling of satisfaction, when seeing a well maintained, working robot. They furthermore highlight the feeling of loss of control when automating tasks in the home. While none of our participants expressed negative feelings of loss of control, a multitude of participants made frequent use of connected systems in order to stay in control and monitor the domestic robots remotely.

One of the findings by Michaelis et al. [31] was the identification for better adaptive behaviour to *augment* the humans' activity. While this recommendation is concerning cobots and the manufacturing setting in industry, our findings are in line with this. Multiple households expressed a desire for more adaptive behaviour from the robot. Instead of the human adapting to the robot, e.g. by leaving the room or pausing the TV when it starts cleaning, the robot should adapt more intelligently to the human.

5.2 Implications and Future Research

While we consider the findings (see Section 4) related to the facilitation of task automation in the home using domestic robots the main contribution, we identified several implications and opportunities for future research. We presented findings illustrating that the task of efficient automation is more complex than buying a robot and pressing start. It requires the development of new routines, preparation as well as maintenance. To improve this, modern domestic robots offer a greater variety of connected devices, thereby improving the development of new ways of interaction, such as voice, touch or remote interaction. We identify three opportunities for future research with the potential for improving interaction as well as unobtrusive task automation with domestic robots.

5.2.1 Timely notifications on planned robot activity. As illustrated the development of new routines is not a trivial task. The ability for non-robotic technology to facilitate the development of routine adoption has already been demonstrated (e.g. [41]). We believe that a more pro-active behaviour from domestic robots can contribute to the development of new routines, thereby preventing breakdowns of automation (e.g. Figure 1a). It would be interesting for future research to investigate if the robot could, using the appropriate timing and means, inform the participants about its intention of cleaning/mowing. Thereby, the robot could take more responsibility, and be pro-active, while still being able to be manually overridden.

5.2.2 Focus on the invisible worker. The desire for the domestic robot to be an invisible worker could be further explored in future research. Most participants expressed that they did not want to see or hear the robot while co-located, preferably while still maintaining a high frequency of operation without being disturbing. This was approached by choosing docking station positions, such as under the couch/beds or in corners of the garden, that allowed for invisibility of the robot. Further, most participants timed the robot operation in a way that minimises co-located operation. Multiple participants stated that the robot runs less frequent - or causing more annoyance - due to the "work-at-home" situation caused by the COVID-19 pandemic. While this is a very specific case, leading to a higher degree of co-location to the robot compared to a usual workweek, the "work-at-home" situation caused deterioration in the frequency of operations (this was especially relevant for indoor domestic robots). It would therefore be interesting to investigate if domestic robots could develop a model about when people are home, or in the same room. This would require the robot to create a model for intention recognition [23], specific to the individual household. Thereby the robot could adapt its routines, using breaks from co-location, to guarantee a satisfying cleaning frequency with less disturbance.

5.2.3 Investigation of under-trust. While most participants used the robot while not co-located, we observed several cases in which this was not the case. The co-located operation was on several occasions related to under-trust in the technologies ability to perform the task without problems. This behaviour was not exclusive for novel robot users. It would be interesting to investigate a way to counter this under-trust in the robot's ability. One way this already is being approached is by more intelligent object recognition behaviour, see Figure 3d. This increases the robots ability to perform, even in cluttered environments, thereby making the automated task completion more reliable. A potential down-side of this is the necessity for a camera on the robot. While multiple of the robots encountered had cameras installed, used for object identification as well as localisation, this brings with it a potential security risk. We found it surprising, that only one household considered this aspect of security, and decided against the preferred robot model since it had a camera.

5.3 Methodological Considerations

Our data collection approach made use of three distinct qualitative methods, namely interviews, contextual technology tours, as well as robot deployment. We believe that the combination of a multitude of different approaches enriches the data by providing a multifaceted view from different perspectives. While most households we recruited for the interviews and the contextual technology tour were already quite accustomed to the robot, the robot deployment approach provided a view from entirely novel users. The combination of both target groups provided valuable data. Examples include the ongoing interest in monitoring the robot while not co-located. While this could be perceived as a novelty effect, the combination of different data collection methods, made it possible to confirm that this was not the case, as even households who have owned domestic robots for a multitude of years still show this behaviour. The combination of multiple data collection methods brings with it the added benefit of increased expressiveness provided by supporting interview data with participant supplied photos. Since the home is a very personal space, letting participants supply photos might have a positive effect on their willingness to share, ultimately leading to richer data [22].

5.4 Limitations

We acknowledge that the study conducted has several limitations. Firstly, the observations made in households can not necessarily be transferred to households outside of Denmark. Trust in robots can change significantly between different cultures. Wang et al. [48] for instance show the difference in trust towards robots between Chinese and US citizens. Therefore the degree of transferability of the here presented results to other cultures is uncertain. Furthermore, the sample of the study, while diverse in terms of income, age, family size or time of robot use, is lacking gender diversity with 22 male and 5 female participants. This limits gender generalisability of the here presented findings.

While it is not easy to define what exactly a robot is, we chose to limit this study to domestic robots, here defined as being vacuuming robots, hybrid robots (which combine vacuuming and floor mopping capabilities), as well as lawn mowing robots. This selection was chosen since these are the primary types of robots that the broad population has access to. Therefore, findings such as presented in e.g. Section 4.1, might not apply to other types of privately owned robots such as robot suitcases. Lastly, while recruiting as diverse as possible, we did not achieve a balance in gender. Only 5/24 households interviewed included female interviewees.

6 CONCLUSION

We investigated task automation for domestic robots in the home. The presented findings illustrate the need to adapt and develop new routines to facilitate the successful task automation of domestic robots in the home. Our contribution to the field of HCI is two-fold. Firstly, the identified themes increase the empirical understanding of how manual labour tasks can be automated using domestic robots. Even though the adaptation of domestic robots creates new and frequent tasks, our data suggest that all 24 participants considered current domestic robots advanced enough to provide real value for the home. Secondly, we highlight three implications for improved automation of domestic robots for future research, leading to opportunities for improved interaction with domestic robots. These are related to a more pro-active behaviour of the robot, a stronger focus on invisible operation, as well as the investigation of participants under-trust towards the robot. Lastly, we discuss our findings in relation to HCI literature investigating different aspects of domestic robots.

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